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Design of Multi-Frequency Antenna with Isolation Enhancement Techniques

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ABSTRACT: This Paper proposes a multi-array antenna which is designed to validate and investigate the various aspects of constraint. The major constraint discussed in this paper is isolation and return loss. The proposed antenna design makes use of triangular geometric shaping and placement of field cancelation line to enhance the isolation. The whole antenna structure is simple and compact and is suitable for cellular phone. The details of antenna design are presented. The mechanism of achieving isolation between the two compact antennas is explained. Finally simulation results are discussed and presented. The method of computation uses MOM and this is enabled by FEKO software.

KEYWORDS*:* MIMO, PIFA, Isolation (S_{21}), Return loss (S_{11})

I. INTRODUCTION

In the last few years multiple inputs multiple output (MIMO) systems have emerged as one of the most promising approaches for high data rate wireless systems. This MIMO antenna is one class of multi-array antenna. In a MIMO system, multiple antennas are used to increase the capacity without the need for additional power or spectrum. Due to the high data rates required in modern personal communications, one should consider to increase the channel capacity of the radio-frequency channel between the base station and the terminal handset. This can be achieved by multiplying the radiating elements involved in the wireless link (diversity and Multiple Input Multiple Output (MIMO) systems) [1]. Due to this reason MIMO plays an important role in 3G and 4G technologies.

MIMO system have attracted significant attention as they have the potential to achieve significant increase in wireless channel capacity without the need for additional transmit power or spectrum [2-4]. According to Shannon, the capacity C of a radio channel is dependent on bandwidth B and the signal-to-noise ratio S/N and "m" number of data or antenna which transmit the data [8]. The following equation applies to a MIMO system:

$$C = m\times B \log_2 (1+S/N) \quad (1)$$

So as the number of antenna increases capacity also increases. There are two major categories of MIMO – spatial diversity, in which the same data is transmitted over each of the multiple paths, and spatial multiplexing, in which each of the paths carries different data. However, the space available for antennas in recent mobile terminal is very limited and it is a big challenge to an antenna designer to reduce the mutual coupling between closely packed antennas for MIMO system [5].

Isolation is a major research area in MIMO antenna system. S21 parameter determine whether the antenna have achieved a good isolation or reduced mutual coupling. The coupling between antennas decreases their efficiencies as part of the power that would normally be radiated which is captured by the other antenna. For many years, numerous studies have been done to find techniques that reduce the mutual coupling between antennas which has been discussed in [1,4,6]. To achieve the reduction of the S21 parameter, the main idea consists in introducing some additional coupling path between the radiators.

Planar inverted-F antennas (PIFAs) have been widely used in mobile terminals because of low profile, less backward radiation and moderate gain. This characteristic is exhibited by folding down the top section of monopole antenna so as to be parallel with the ground plane. This is done to reduce the height of the antenna, while maintaining a resonant trace length.

The remainder of the paper is structured as follows. Section II describes the antenna design with its dimension. Section III describes the detail analysis of isolation enhancement technique. Section IV describes the various results that are obtained from the experiment. Lastly Section V concludes the discussion.

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II. ANTENNA DESIGN

The geometry of the proposed antenna with detailed dimensions is shown in Fig. 1.

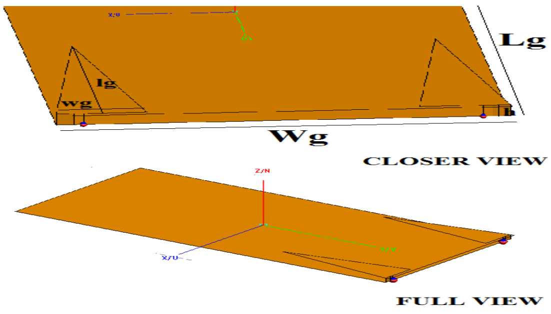

Fig. 1: Proposed antenna design

The ground dimension is 110 mm × 40 mm which can be considered to be as the circuit board of a mobile handset. The value of dimension above is shown in table 1. Here "Wg" and "Lg" represents Width and Length of the ground plane of MIMO antenna. "wg" and "lg" represents width and length of radiating plane. "h" represent the height of the stub. Here the two radiating planes are perpendicular to each other and the field cancellation line (neutralisation line) is placed between the two planes in order to increase the isolation. The material that we use is perfect electric conductor.

TABLE 1: DIMENSION OF PROPOSED MIMO ANTENNA (UNIT: mm)

Wg	Lg	wg	Lg
40	110	10	24

With this design dimension, resonance frequency can be calculated (Fr) [3] .

$$Fr=c4\times(lg+Wg-h) \quad (2)$$

The resonance frequency achieved from the proposed antenna is in the band of frequency of 2.4 – 2.7 GHz. At the considered frequency band, the two PIFAs are approximately half- wavelength apart and therefore the spatial fading correlation shall not impose major limitations. The electromagnetic coupling between the two antenna PIFA elements is found very high.

To reduce the mutual coupling, antenna is placed in such a way so that it is perpendicular to each other. The basic idea behind orthogonal placement is to separate the radiation apart from two antenna. In addition to it the concept of field cancelation line (neutralization line) is introduced to enhance the isolation.

III. SIMULATION AND RESULTS

A. Placement of PIFA Antenna

The main problem in MIMO systems is to find the right place to put the antennas. It has been found that the corners of a rectangular ground plane are optimal places for patch type antenna elements, because the electric field of ground plane resonant modes would be maximal in these locations.

Thereupon there are three possibilities to situate the antennas. At the corners in the top or bottom of the ground plane, at the corners in the left or right side of the ground plane and one in a corner of the top of the ground plane and the other one in the opposite corner in the bottom.

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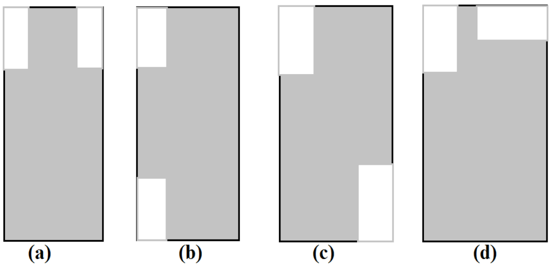

Fig. 2: Placement of PIFA antenna in ground plane

From fig.2 parallel configuration is chosen so that the dimension is compatible with the mobile phone. The spacing between the two antenna elements is 20 mm.

Now fig 1 and fig 2 are considered and simulated. There return loss and isolation is observed. When simulation of both the configuration is done, it is found that there is drastic shift in frequency.

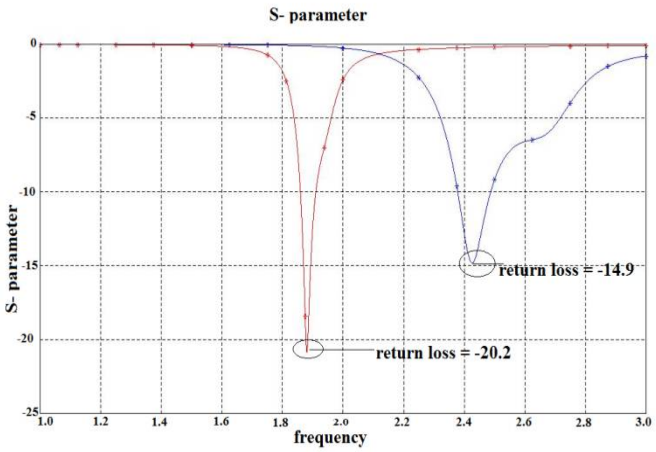

Fig. 3: Return loss of Parallel and triangular shaped antenna

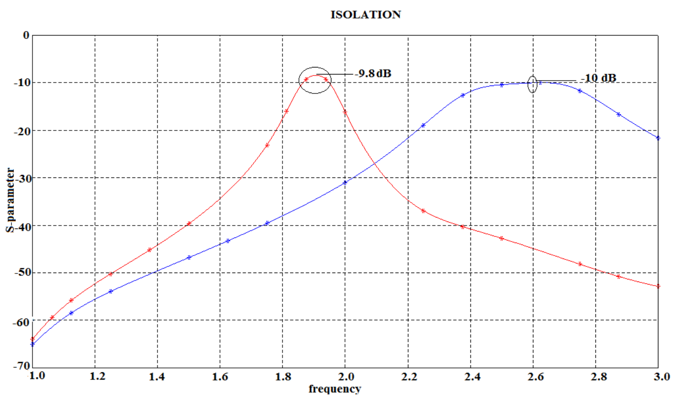

Fig. 4: Isolation of Parallel and triangular shaped antenna

The parallel antenna element have better return loss coefficient (-20.2 dB) than triangular shaped antenna element (-14.9 dB) but the specified value of return loss for any antenna to work properly is -6 dB which both the antenna configuration is achieving. This is shown in fig.3

Fig.4 shows that the isolation achieved by triangular shaped antenna (-10 dB) is much better than parallel antenna (-9.8 dB). The isolation achieved by orthogonal placement is 0.2 dB more than the parallel configuration. This result is not much satisfactory but can be a factor for enhancement in isolation when we introduce neutralisation line.

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B. *Placement of Field Cancellation Line*

Before the placement of neutralization line the antenna is analyzed with the radiation pattern .The concept introduced is simple. Here first antenna element is excited with 1v and second element is shorted with 50 ohms wire. From radiation pattern that is shown in fig 5(a) it can be inferred that the radiation is more toward the left hand side with some side lobes. In second case the first element is shorted with 50 ohms and second element is excited with 1v . From radiation pattern that is shown in fig 5(b) it can be observed that radiation is more towards right hand side.

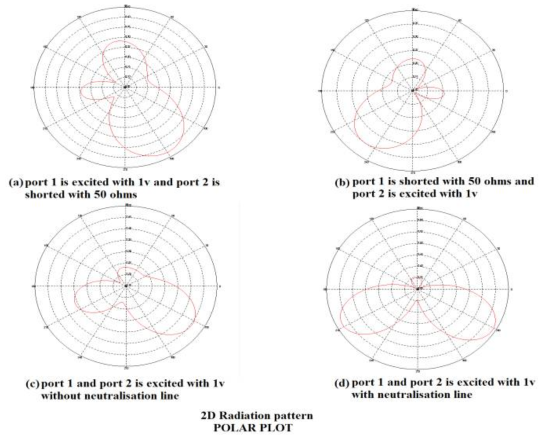

Fig. 5: Polar plot of antenna without and with neutralization line

In the third case both the antenna element is excited with 1v and it is observed that in fig 5(c) that two radiation is bulging out with some separation but it is not enough to have good isolation, so in the last case that is in fig 5 (d) enhancement of isolation was considered where both the antenna element was excited with 1v with neutralization line and it was found that there is a significant separation of radiation compared to fig 5(c).

When a Neutralization line is placed between the two stub good isolation is achieved. But by the thorough understanding of current distribution in the radiating plane, placement of neutralization line became a significant factor. So it is important to understand the current distribution of the antenna before going for the placement of neutralization line.

C. *Method of Moment (MOM)*

The fundamental concept behind the MoM employs orthogonal expansions and linear algebra to reduce the integral equation problem to a system of simultaneous linear equations. This is accomplished by defining the unknown current distribution $I_z(z')$ in terms of an orthogonal set of “basis” functions and invoking the boundary conditions—the values of the electric field on the surface of the wire and in the feed gap—through the use of an inner product formulation.

The solution procedure begins by defining the unknown current distribution $I_z(z')$ in terms of an orthogonal set of basis functions. Two categories of basis functions exist. Sub-domain basis functions, significantly more popular in industry, subdivide the wire into small segments and model the current distribution on each segment by a simple geometrical construct, such as a rectangle, triangle, or sinusoidal arc. The amplitudes of these constructs represent the expansion function coefficients.

Entire domain basis functions employ a more formal orthogonal expansion, such as a Fourier series, to represent the current distribution along the entire wire. Entire domain basis functions tend to yield more complicated calculations for the so-called impedances and, therefore, are less popular.

The introduction of the redefined current distribution reduces the integral equation to the form

$$\sum_{n=1}^{N} C_n G_n(z) = E_z(z) \qquad (5)$$

Where

$$G_n(z) = \frac{1}{j4\pi\omega\varepsilon}\int_{-l/2}^{l/2} F_n(z')\left[\frac{\partial^2}{\partial z^2}+k^2\right]\frac{e^{-jkR}}{R}\,dz' \qquad (6)$$

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Cn = Current's expansion coefficient
Fn(z')= Basis function

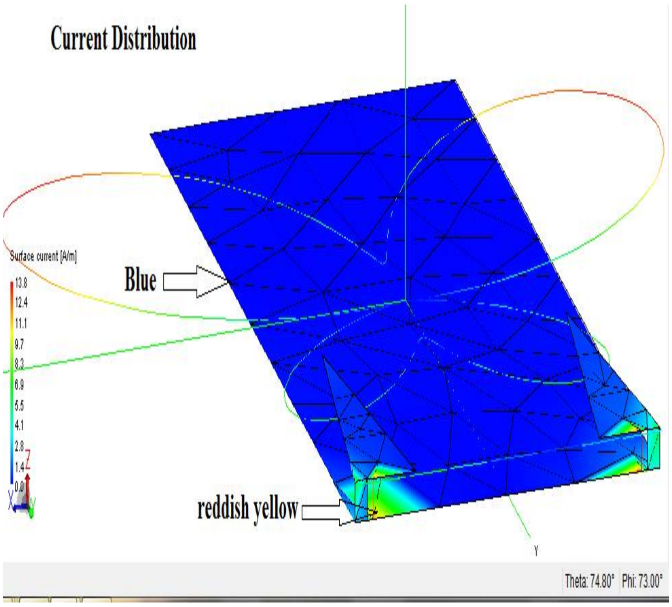

Fig. 7: Current distribution on the proposed MIMO antenna

Current distribution of proposed antenna is shown in fig.7.In this figure a scale is given which tells about surface current represented in unit of Ampere per meter. As shown in fig.7 the blue is inactive current that means the charge is stagnant and as we go up the scale the current increases which means the moment of charge increases and it is maximum in red point. As explained in previous topic current 'I_z' is distributed along the PIFA radiating plane so we take surface integral current to find out the overall current distribution.

When we place the field cancellation line on the area called as red zone where moment of charge is maximum, enhanced isolation is achieved. This same concept is applied in the combination of orthogonal and neutralization line.

D. Triangular Geometry PIFA antenna

As shown in Fig 2 there are various ways an antenna can be placed to obtain good efficient antenna. As told earlier triangular geometry does not yield satisfactory results but can be a factor to improve the isolation, this can be explained by the current distributed theory. As shown in Fig 7 the area of triangular is much smaller than the area of rectangle. So the current distributed is much less in case of triangle than the rectangle so as a result it leads to decrease in mutual coupling. Hence triangular geometry becomes a factor for increase in isolation.

E. Triangular shaped PIFA antenna with neutralization line

Considering the above theoretical analysis both triangular geometry and neutralization line is implemented in the proposed antenna in order to achieve good isolation. Apart from isolation the important parameter is return loss and is crucial in antenna designing as it gives information whether the antenna will work or not.

With the combination of orthogonal and neutralization line return loss obtained is -34.9 dB. As we know the threshold point which has been set in order for an antenna to work is -6 dB. Now our main concern was to achieve better isolation. As shown in graph below it is observed that isolation of -52.5 dB is achieved.

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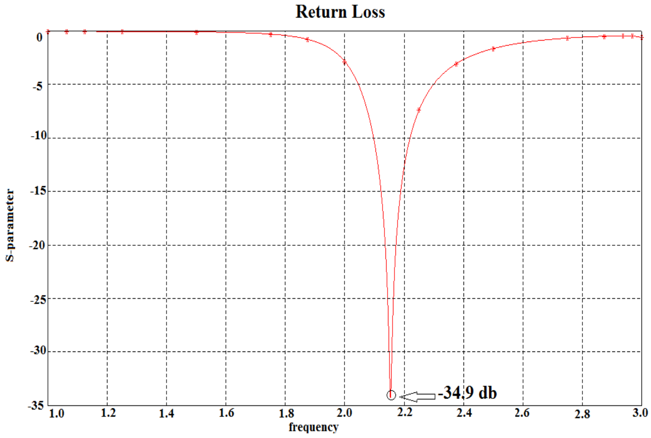

Fig.8 Return loss of proposed antenna

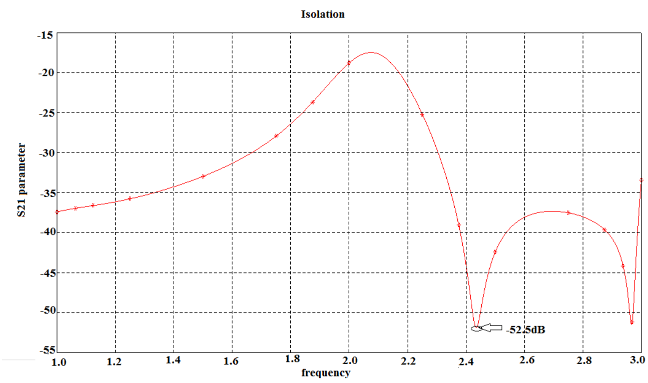

Fig.9 Isolation of proposed antenna

The overall antenna efficiency including the effect of mutual coupling is simulated and calculated by the following equation

$$\eta_{total}= \eta_{radiation} (1-|S_{21}|^2) \quad (7)$$

Where η_{total} is the total efficiency including the effect of mutual coupling and $\eta_{radiation}$ is the radiation efficiency. The overall antenna efficiency of the proposed integrated PIFA excited from port1 and port 2 is about 70%.

Simulated antenna peak gains of the proposed antenna design excited from port 1 and 2 at 2.25 GHz are about 5.29 dB . Apart from it antenna power loss is 0.001011 W which is very small. There has to be a trade off maintained between isolation and return loss. So there is a point in isolation were antenna efficiency decreases with return loss. The 3D radiation pattern of orthogonal and neutralization line antenna is shown fig.10 (a). Radiation pattern in 2D Polar plot is also shown in fig 10(b).

The results show that the proposed antenna is very suitable for different mobile devices, such as a mobile phone, PDA, laptop, etc.

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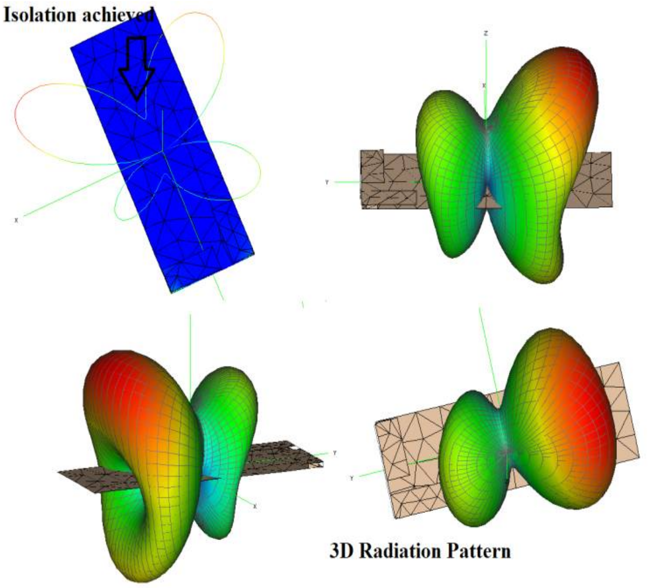

Fig. 10: (a) 3D radiation pattern obtained from proposed antenna

Radiation pattern of 3D plot and Polar plot are same. Polar plot is plotted for more clarity. From the graph it can be clearly seen the separation of radiation between two PIFA antenna

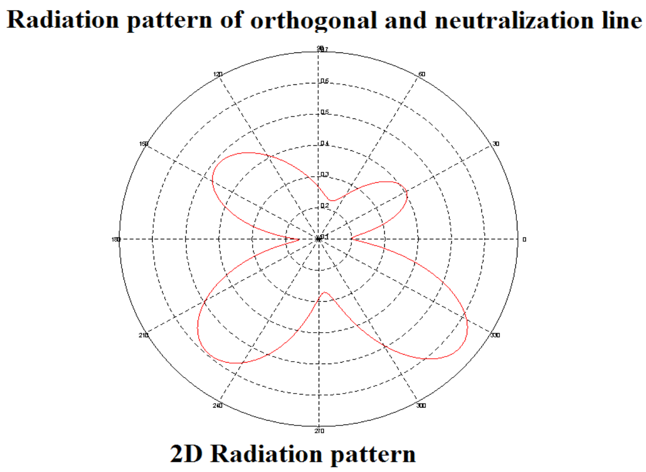

Fig. 10: (b) Polar plot of proposed antenna

IV. CONCLUSION

The proposed MIMO antenna with dimensions compatible with a mobile phone has been designed. First the concept of orthogonal placement of antenna was explained and their return loss and isolation was analyzed. Similarly in case of neutralization line, return loss and isolation was analyzed. Then the concept of current distribution which leads to important conclusion of placement of neutralization line which tells that when we place the field cancellation line on the area called as red zone where moment of charge is maximum(current distributed is more), enhanced isolation is achieved.

Finally the implementation of proposed antenna was carried out and parameters like isolation return loss and antenna efficiency was investigated. It was found that the isolation achieved was -52.5 dB which is found to be good and it can be evident by considering radiation pattern. In addition to good antenna performance, the simple structure and low-cost features also make the proposed design very suitable for wireless communication applications.

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